Effect of Seed and Fertilizer Subsidies on the Technical Efficiency of Rice Farmers in Senegal

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ABSTRACT

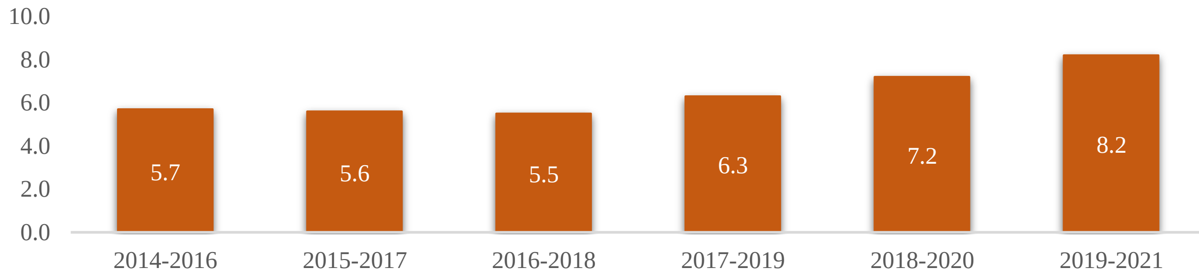
The aim of this study was to analyze the effect of seed and fertilizer subsidies (NPK and urea) on the technical efficiency of rice farmers in Senegal. Using data from the Annual Agricultural Survey (EAA) of the Directorate of Analysis, Forecasting and Agricultural Statistics of Senegal (DAPSA), the results of Stochastic Frontier Analysis (SFA) revealed that rice farmers in Senegal have on average a technical efficiency level of 0.545. This suggests that they could increase their current production by 45.5% while using the same level of inputs. Estimation of an SFA model for technical inefficiency revealed that seed and urea subsidies have a significant effect on reducing technical inefficiency. A farmer using subsidized seed saw a reduction in technical inefficiency level by 10.5% and using urea was associated with a 5.1% decrease in inefficiency. In contrast, the model showed no association between the use of subsidized NPK or the use of herbicides and technical inefficiency. And use of organic fertilizer was estimated to worsen technical inefficiency by 4.4% (perhaps reflecting greater reliance on lower-cost inputs among less productive farm households in Senegal). With regard to socio-demographic factors, the results further revealed older respondents experienced more severe technical inefficiency, and that women on average were 9.6% more inefficient than men. These barriers to improved efficiency among older farmers and women suggest targeted supports may be necessary alongside general subsidy programming.

Keywords: Seed subsidy; Fertilizer subsidy; Technical efficiency; Rice; Senegal

I. INTRODUCTION

While still suffering the devastating consequences of the Covid-19 pandemic, the world is now facing a new food crisis caused by the Russian-Ukrainian conflict. In Senegal, this situation has resulted in an increase in food insecurity, which was already at a high level. Indeed, between 2014 and 2021, the number of people in a situation of moderate to severe food insecurity increased from 5.7 to 8.2 million (Figure 1) out of a total population of 16.2 million in 2019 (ANSD, 2022). In other words, about one out of two Senegalese currently lives in a situation of food insecurity.

Figure 1. Moderately and severely food insecure in Senegal (millions, 3-year average).



*Source***:** Authors, FAOSTAT data (23/12/2022)

Rice is the main staple food of Senegal. Its average annual consumption is around 100 kg/inhabitant, corresponding to an average daily consumption of around 300 g/inhabitant, thus making Senegal one of the largest rice consumers in West Africa (Villar, 2019). Despite this strong demand, national production only covers 45% of the country's consumption needs (FAOSTAT, 23 Dec-2022). To meet growing demand, Senegal relies on imports mainly from East Asian countries, including Vietnam, India, China and Pakistan. Indeed, according to the United States Department of Agriculture (USDA), the country imported 1.1 million tonnes of milled rice in 2021.

However, since the 2008 food crisis which led to an increase in the price of rice at the international level, state authorities have been acutely aware of the vulnerability of the country to depend on outside sources for food. This led to formulation of the National Program for Self-sufficiency in Rice (PNAR) through the Great Agricultural Offensive for Food and Abundance (GOANA). The objective of this program was to achieve self-sufficiency in rice and ensure food security. In 2012 the PNAR was revised and strengthened through the Senegalese Agriculture Acceleration Program (PRACAS), the agricultural component of the Emerging Senegal Plan (PSE). This is how the objective of self-sufficiency in rice was extended to 2017, with the target of producing 1.6 million tonnes of paddy to fully cover the country's domestic demand (PRACAS, 2014).

The PSE remains the current public policy framework for economic and social development in Senegal. Implemented since 2013, this plan aims to make Senegal an emerging country by 2035. It revolves around three strategic axes, namely:

Axis 1: Structural transformation of the economy and economic growth;

Axis 2: Investment in human capital, social protections and sustainable development; and

Axis 3: Governance, institution, peace and security.

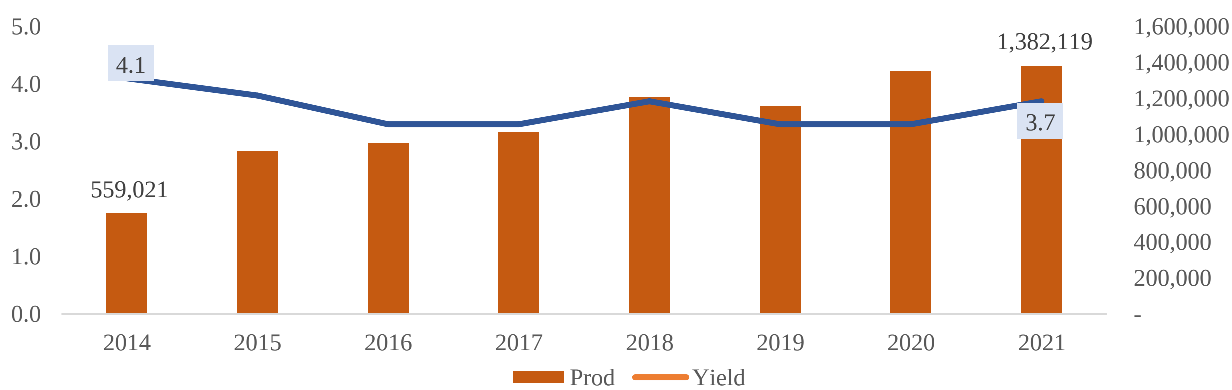
To support the sector and enable it to achieve the objectives of the PRACAS, over the past decade the Government of Senegal has established a major agricultural input subsidy program allowing beneficiary producers to have access to fertilizers, seeds and agricultural equipment at reduced prices, sometimes less than 50% of the market price (IPAR, 2015). During the 2020-2021 agricultural season, the state authorities allocated 55.9 billion Central African francs (FCFA) to this program (27.3 billion FCFA for seeds, 23.7 billion for fertilizers and 4.1 billion for agricultural equipment) (USDA, 2020).

Given the prominent place it occupies in the PRACAS, the rice sector benefits from a considerable share of this subsidy program. However, notwithstanding the efforts made by the State of Senegal in this sector, the objective of self-sufficiency in rice has not yet been achieved. Indeed, the country's national production was estimated at 1 million tonnes of paddy in 2017 (FAOSTAT, 23 Dec-2022) in spite of a target of 1.6 million tonnes. Critics allege that instead of identifying reasons for the failure of this program to achieve the target goal, the government has simply postponed its objective of self-sufficiency in rice to 2023, with a new projected production of 2.1 million tons of paddy through the 2nd Adjusted and Accelerated Priority Action Plan (PAP2A).

Rice production can be enhanced by increasing sown areas, technological change or improving the technical efficiency of rice farmers (Javed et al., 2010). Javed et al. (2010) conclude that improving technical efficiency is the most appropriate in the short term because it does not require more sown area, and allows for higher cropping intensity via development and adoption of new technologies. Agricultural intensification via improved technical efficiency also supports the sustainable development objective of producing more with fewer resources in order to reduce greenhouse gas emissions. A focus on technical efficiency therefore makes it possible to consider whether a farm is making optimal use of existing technology, i.e., whether it might be capable of obtaining, at a given level of production inputs, a higher level of production (output orientation); or if it might use, at a given level of production, a reduced amount of inputs (input orientation).

In Senegal, while rice production has increased from 559,021 tonnes in 2014 to an estimated 1,382,119 tonnes in 2021, rice yield has decreased from 4.1 to 3.7 t/ha over the same period (Figure 2). This means that the increase in production has been primarily driven by expansion in planted area and not improvement in the productivity of rice farmers. Therefore, this paper asks: is there any evidence that subsidies granted to producers have improved their technical efficiency?

Figure 2. Evolution of production (in tonnes) and rice yield (in t/ha) in Senegal.



Source: Authors, FAOSTAT data (23/12/2022)

For the past decade, researchers have been interested in the role of public subsidies received by farmers in their decisions on production and use of production factors, and therefore their technical efficiency (Latruffe, 2018). In Senegal, Seck (2016) used Data Envelopment Analysis (DEA) in an effort to explore subsidy impacts, however this early work only considered fertilizer subsidies. This article uses a Stochastic Frontier Analysis (SFA) model to analyze the effects of the full range of agricultural input subsidies including seeds as well as fertilizers (NPK and urea) on the technical efficiency of rice farmers in Senegal. The paper proceeds as follows: Section II summarizes Senegal's agricultural input subsidy program, and Section III presents a selective review of the literature on evaluation of productivity impacts of subsidy programs. Data and methods are presented in Section IV, and Section V presents and discusses findings from the study. The final section concludes with consideration of policy recommendations.

II. SENEGAL AGRICULTURAL INPUT SUBSIDY PROGRAM

The Agricultural Input Subsidy Program in Senegal works as follows:

The State, through its structures for supervision, support and agricultural advice, in particular the Company for the Development and Exploitation of the River Delta and the Senegal River Valley (SAED) and the Agricultural and Industrial Development Company of Senegal (SODAGRI), assesses each crop's seed and fertilizer requirements for each crop at the start of the campaign according to regional production objectives, planned plantings and recommended fertilizer doses to achieve production objectives. Then, it subsidizes, subject to the budgetary limits provided by the Ministry of Finance in agreement with the Ministry of Agriculture and Rural Equipment, the quantities of inputs transferred to producers by input suppliers. However, distribution remains the responsibility of the suppliers.

Subsidized certified seeds are distributed by private seed companies or directly by the Senegalese Agricultural Research Institute (ISRA), which is responsible for producing quality inputs. Once the quantities of subsidized fertilizers and seeds are known at the regional level, they are distributed at the level of each rural municipality where a "Cession Commission" is responsible for distributing them among the producers. Exact subsidy levels vary by input and crop. Thus, for the 2022-2023 agricultural campaign, the subsidy rate was set at 50% by the state authorities (Ministry of Agriculture). However, due to relatively insufficient quantities of subsidized inputs, not all farmers benefit from this program.

Under the authority of the Ministry of Agriculture and Rural Equipment (MAER), a Local Commission (CL) is set up for each local authority and has the task of receiving and distributing agricultural inputs, ensuring the regularity, traceability, transparency and fairness in the operations of distributing and selling agricultural inputs. It monitors the safety and quality of the agricultural inputs put in place and is also responsible for reporting, on a weekly basis, to the Prefect or Sub-Prefect.

The Local Commission is responsible for:

(i) Selecting agricultural households that benefit from agricultural inputs in the commune;

(ii) Prioritizing the selection of producers registered in the Unified National Register (RNU);

(iii) Overseeing, in the Commune, the progress of the operations, in particular the quantities distributed per beneficiary, the identity of the beneficiaries (First name, Surname, place of residence, etc.) and the progress of the operations (regularity, transparency, possible difficulties, etc.); and

(iv) Establishing the sales journal which traces and identifies all the beneficiaries of these inputs.

In reality, this subsidy program does not always work as indicated above. Indeed, the IPAR report (2015) revealed that the criteria for selecting the beneficiaries of these subsidies are little known and vary according to the commissions given that they are often made up of local politicians, administrative authorities, leaders of village organizations, etc. According to this report, a massive diversion from the objectives in the distribution of subsidized agricultural inputs and equipment is noted, insofar as resources intended for Senegalese farmers' fields are sometimes trafficked to neighboring countries, contributing to a loss of public resources. In addition, subsidized inputs are often not available on time, resulting in a late start to the agricultural season. The lack of transparency noted in the selection of beneficiaries, the absence of a reliable information system, and the difficulty of tracing the path of subsidized inputs have led several actors to express doubts on the merits and ultimately on the effectiveness of this agricultural subsidy program.

III. SELECTED REVIEW OF LITERATURE

In this section, we present a selective review of the literature on the effect of agricultural subsidies on the technical efficiency of farmers.

3.1 Theoretical literature on the effect of agricultural subsidies on technical efficiency

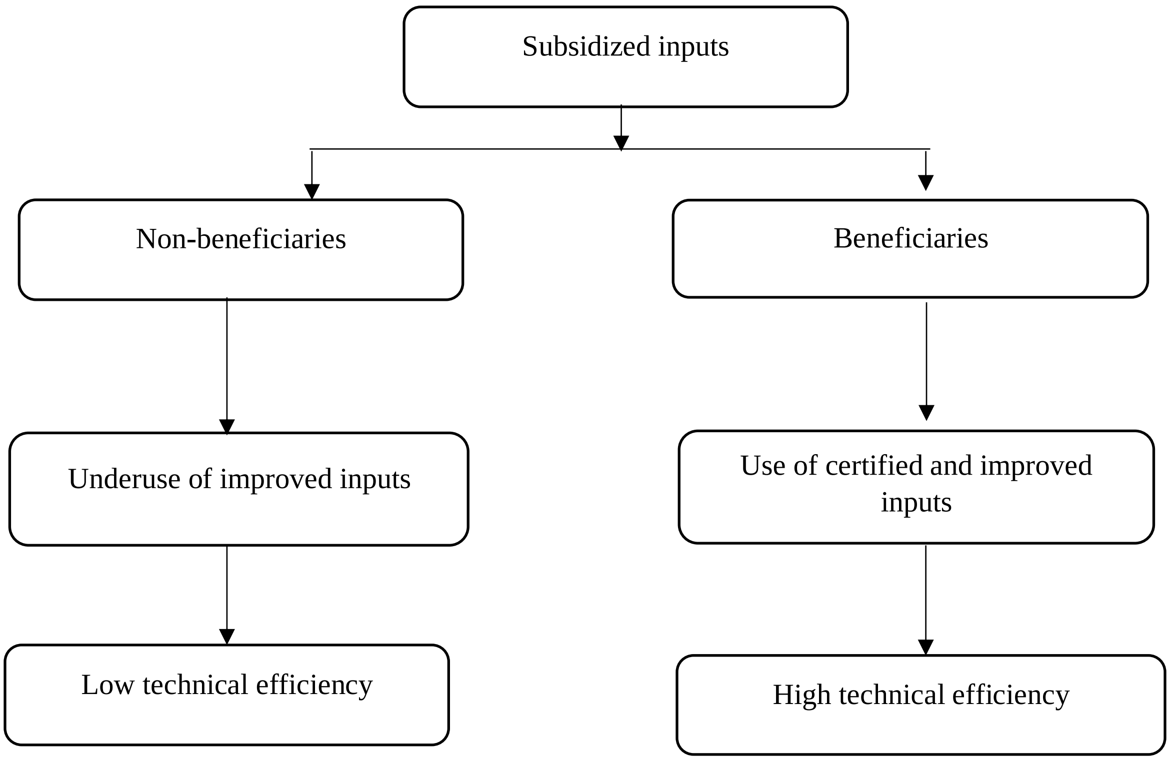
By reviewing the existing literature on the link that may exist between agricultural subsidies and the technical efficiency of farmers, we find that authors are divided on the issue. Indeed, while some consider that the subsidies received by farmers contribute to improving their level of technical efficiency, others believe that these could have a negative or even zero effect on the technical efficiency of production.

Positive impacts would result from the fact that the subsidies help overcome certain production constraints such as access to credit and agricultural mechanization (Garrone & al., 2018; Góral, 2015) and hence increase the efficiency of the producer (Zhu & al., 2012; Zhu & Lansink, 2010). Subsidized inputs are also often certified by the technical units of the Ministry of Agriculture, notably the Senegalese Institute of Agricultural Research (ISRA). The use of quality inputs could therefore improve the technical efficiency of rice farmers who benefit from them (Figure 3).

Potential negative effects of subsidies would come from the income effect (Minviel & Latruffe, 2017; Zhu & Lansink, 2010; Young & Westcott, 2000) and the insurance effect (Burfisher & Hopkins, 2003; Lopez, 2001); Hennessey (1998). Both have the potential to reduce producer effort and hence technical efficiency (Martin & Page, 1983).

Subsidies may also have no effect on the technical efficiency of production because this is not the main objective of the subsidy policy (Latruffe, 2018). This is why some authors including Kumbhakar & Lien (2010) and Zhu & Lansink (2010); Serra, Zilberman & Gil (2008) maintain that the study of the link between agricultural subsidies and technical efficiency is essentially an empirical question.

Figure 3. Conceptual framework of the effect of agricultural subsidies on technical efficiency.



Source: Authors

3.2 Empirical review of the effect of agricultural subsidies on technical efficiency

Researchers are increasingly interested in the role of public subsidies received by farmers in their decisions about production and the use of production factors.

Minviel & Latruffe (2017) listed the empirical results of 68 studies conducted between 1986 and 2014, i.e. a total of 195 estimated models. Their result revealed that 60% of these models found a negative association between public subsidies and technical efficiency, 24% showed a positive association and 16% indicated that public subsidies have no effect on technical efficiency. These authors then conducted a meta-analysis to identify the source of differences between the results of these 195 models. This meta-analysis revealed that the direction of the effect (positive, negative or null) depended on how the subsidies were integrated into the model. These authors also underlined the importance of the type of subsidy in the diversity of the results.

Using the SFA model, Pechrova (2015) assessed the impact of subsidies on the technical efficiency of farmers in the Liberecky region. The study revealed that direct payments and agri-environmental payments tended to increase inefficiency, while subsidies aimed at the most disadvantaged areas positively affected the technical efficiency of farms.

Naglova & Pechrova (2019) assessed the effect of subsidies on the technical efficiency of food processing companies using an SFA model. Their result revealed that the technical efficiency of companies without subsidies was higher than those subsidized, though it differed significantly over time and also in relation to the region where the company is located.

Staniszewski & Borychowski (2020) analyzed the impact of European Union Common Agricultural Policy (CAP) subsidies on the technical efficiency of farms, depending on farm size. Using another SFA model, the authors found that the impact of subsidies on technical efficiency depended on farm size. Indeed, the study showed that subsidies had a positive and significant impact on the technical efficiency of large farms, while they had no effect on that of small farms. Kostlivy & Fuksova (2019) found a similar result indicating that different types of subsidies can have different impacts on the technical efficiency of farms of different sizes.

The study by Latruffe & Desjeux (2016) goes further by evaluating the impact of CAP subsidies not only on annual technical efficiency, but also on the evolution of technical efficiency from one year to the next. These authors reported that, although the subsidies had a negative impact on annual technical efficiency over the period 1990-2006, they improved technical efficiency from one year to the next.

In Africa, Chiromo (2018) analyzed the impact of the Agricultural Input Subsidy Program (FISP) on the technical, allocative and economic efficiency of smallholder maize farmers in Malawi. Estimation of a Tobit model revealed that this subsidy program significantly improved the technical efficiency of these producers.

Imoru (2015) used an SFA model to assess the effect of fertilizer subsidy on the technical efficiency of smallholder farmers in Ghana. The study showed that participants' technical efficiency increased with the use of subsidized fertilizers.

In Senegal, Seck (2016) used a Data Envelopment Analysis (DEA) model to show that the fertilizer subsidy program has indeed contributed significantly to improving the productive performance of farmers in the Senegal River Valley. His empirical results tend to validate the assumptions that lower fertilizer prices, as a result of subsidies, induce farmers to use more inputs, which subsequently results in increased production.

By browsing the existing literature, we see that the empirical results differ not only in the context of the studies but also in the data used and also in the approach taken to address the issue.

IV. DATA AND METHODS

4.1 Data

The data used in this study come from the Senegal Annual Agricultural Survey (AGRIS survey) of the Department of Analysis and Forecasting of Agricultural Statistics (DAPSA) for the 2020-2021 agricultural season. The AGRIS survey is a multi-annual modular agricultural survey program. The AGRIS methodology is developed by FAO as part of a global strategy to improve agricultural and rural statistics. It constitutes a source of data and a framework for the design, monitoring and evaluation of agricultural or rural policy or investment. In addition, it is a tool for providing direct information for certain indicators on the Sustainable Development Goals (SDGs).

Since the 2017 campaign, DAPSA has benefited from the AGRIS Survey program competition. The objective of the project is to develop and implement a new approach to broaden the domains of the Annual Agricultural Survey (AAS) in order to collect and disseminate more varied agricultural data in the context of developing countries. Its implementation in Senegal consisted of adapting the EAA system to an expanded survey using a multi-year modular approach, the basic module of which constituted the 2017-2018 survey.

The EAA 2020-2021 database includes a total of 1481 plots exploited throughout the national territory whose main crop is rice. However, given the fact that the survey only collects annual production at the household-level (not the plot level), we only consider households that farm a single plot of rice, allowing us to construct an accurate yield measure – our main outcome of interest – and test associations between other plot-level characteristics in the survey data (plot size, input use (Table 1)) and yield. After eliminating multi-plot rice households, we have 393 plots which constitute our working sample.

4.2 Variable definitions

The model variables are explained in the table below.

Table 1. Description of variables in the study.

Variable	Definition
Rendem	Yield: Quantity of rice produced in the plot in Kg per Hectare
Qtité_semence	Quantity of seeds used in the plot in Kg
Taille_parcelle	Plot size in Hectares
Taille_ménage	Household size: Number of people living in the household
Qtité_NPK	Quantity of NPK fertilizer used in the plot in Kg
Qtité_urée	Quantity of Urea applied in the plot in Kg
Semence_subv	Binary variable, 1= If the producer received subsidized seeds; 0= No
NPK_subv	Binary variable, 1= If the producer received subsidized NPK; 0= No
Urée_subv	Binary variable, 1= If the producer received subsidized urea; 0= No
Engrais_org	Use of organic fertilizer: 1= Yes; 0= No
Herbicides	Use of herbicides: 1= Yes; 0= No
Age	The age of the plot manager in years
Sexe	Gender of plot manager: 1= Female; 0= Male
Statut_matrim	Marital status of plot manager
Niv_scolaire	Education level of plot manager
Crédit	Binary variable, 1= If farmer received credit; 0= No

*Source***:** Authors

4.3 Stochastic Frontier Analysis (SFA) model specification

Formulated by Aigner & al (1977), the SFA model is a parametric approach that measures the technical efficiency of a producer. It uses the basic formula of the Cobb Douglas production function, its general formula is written as follows:

$$Y_{it} = f(X_{it}, \beta) \exp (V_{it}) \exp (-U_{it}) \quad (1)$$

Where

Y_{it} represents the output of producer *i* at date *t*,

X_{it} represents the vector of inputs used by producer *i* on date *t*,

β represents the vector of parameters to be estimated,

$V_{it} \sim N(0, \delta_v^2)$ and $U_{it} \sim N^+[f(u, \alpha), \delta_u^2]$ are respectively the error term and the inefficiency of producer *i* at time *t*. The inefficiency term *U* follows a positive normal distribution with a constant variance δ_u^2 and a parameter μ which depends on the additional explanatory variables.

Specifically, $\mu = \alpha z$ (2)

Where

$\boldsymbol{\alpha}$ is the vector of parameters to be estimated.

According to the standard approach, the determinants of technical efficiency can be estimated simultaneously using the production frontier drawn in equation (1) and an equation for the effect of inefficiency specified by Battese & Coelli (1995) as follows:

$$U_{it} = f(\mu_{it}, \alpha) \quad (3)$$

Thus, the technical efficiency of producer *i* is given by the following equation:

$$ET_{it} = \frac{Y_{it}}{Y_{it}^*} = \frac{f(X_{it}, \beta)\exp\,(V_{it} - U_{it})}{f(X_{it}, \beta)\exp\,(V_{it})} = \exp\,(-U_{it}) \quad (4)$$

Where

$Y_{it} = f(X_{it}, \beta)\; exp\; (V_{it} - U_{it})$ represents production observed with inefficiency.

$Y_{it}^* = f(X_{it}, \beta)\;\exp\;(V_{it})$ represents the production frontier without inefficiency.

By linearizing the Cobb Douglas production function and the inefficiency function, we obtain:

$$lnY_{it} = \beta_0 + \beta_{it} \sum_{i=1}^{n} lnX_i + V_{it} + U_{it} \quad (5)$$

$$U_{it} = \alpha_0 + \alpha_1 Subv + \sum_{i=1}^{n} \alpha_i\, m_i + Z_i \quad (6)$$

Where

Y_i represents the rice output;

X_i is a vector of inputs;

β_0 , β_i , α_0 , α_1 and α_i are parameters to be estimated;

m_i represents the vector of control variables in the model;

U_i represents the inefficiency of the rice farmer which follows a truncated normal distribution;

V_i is the random error term that follows a normal distribution in the production function; while Z_i is a random error term for the inefficiency function; and

$Subv$ refers to agricultural input subsidies granted to the producer.

To determine the existence of inefficiency, Battese & Coelli (1995) recommends the use of gamma (γ) after the stochastic frontier analysis.

The log-Likelihood function is parameterized as follows:

$$\delta^2 = \delta_v^2 + \delta_u^2 \quad \text{and } \gamma = \delta_u^2/\delta^2 \text{ with } 0 < \gamma < 1. \quad (7)$$

The γ value is used as an indicator to measure the influence of inefficiency on the variance (Bravo-Ureta & al. 2012). In case γ is close to 1, implies that the boundary deviation dominates the total variance and γ=0 means that there is no inefficiency on the total variance due to the truncated normal random variable U_i which is equal to $\left(\frac{\pi}{2} - 1\right) \delta_u^2$.

Taking into account the variables of the study, the empirical model is written as:

$$ln(Rendem) = \beta_0 + \beta_1\, ln(Qtité\_Semences) + \beta_2\, ln(Taille\_parcelle) + \beta_3\, ln(Qtité\_NPK) + \beta_4 ln(Qtité\_Urée) + \beta_5\, ln(Taille\_ménage) + (v_i - u_i) \quad (8)$$

And the technical inefficiency function is written as:

$$u_i = \delta_0 + \delta_1(Semence\_subv) + \delta_2(NPK\_subv) + \delta_3(Urée\_subv) + \delta_4(Engrais\_org) + \delta_5(Herbicides) + \delta_6(Crédit) + \delta_7(Age) + \delta_8(Sexe) + \delta_9(Statut\_matrim) + \delta_{10}(Niv\_scolaire) \quad (9)$$

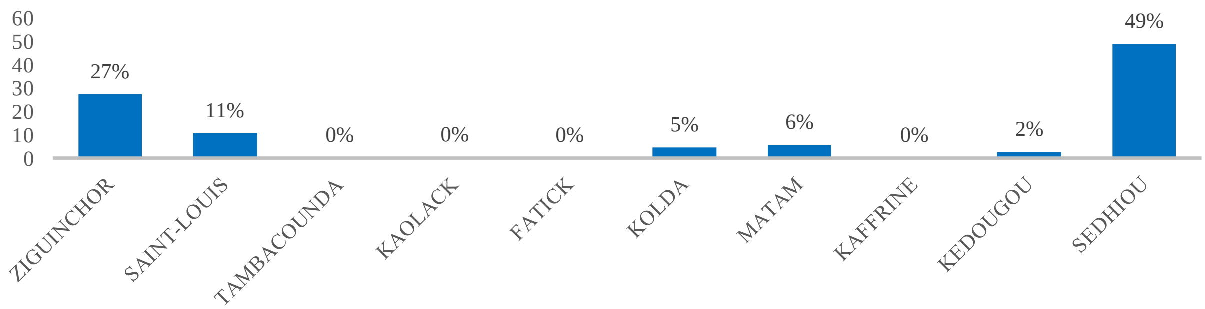
The SFA model was estimated using Stata software based on the three stages of the estimation methodology proposed by Coelli & al (1996): (1) Ordinary least squares (OLS) estimation of the production function; (2) a double-hurdle model for $\gamma = \sigma u^2 / (\sigma u^2 + \sigma v^2)$ which goes from zero to one and is driven by parameters β (except β_0) and the parameters β_0 and σ^2 are adjusted according to the corrected MCO presented in Coelli & al (1996); (3) the values selected in the first stage are used as starting values in an iterative procedure (using the Davidon-Fletcher-Powell quasi-Newton method) to obtain the final estimate.

5. RESULTS AND DISCUSSION

5.1 Descriptive statistics

The distribution of respondents by region (Figure 4) highlights that the sample of rice farmers is mainly drawn from the regions of Sédhiou (49%), Ziguinchor (27%), Saint Louis (11%), Matam (6%) and Kolda (5%). The Casamance (Ziguinchor, Sédhiou and Kolda) accounts for 81% of the sample of rice-growing farmers.

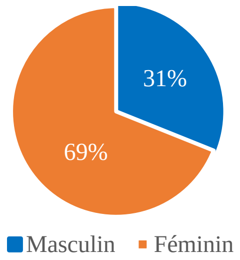
Figure 4. Respondents by region (%).



Source: Authors, EAA 2020-2021

The distribution of plot managers by gender (Figure 5) shows that rice growing is mainly practiced by women who represent 69% of plot managers.

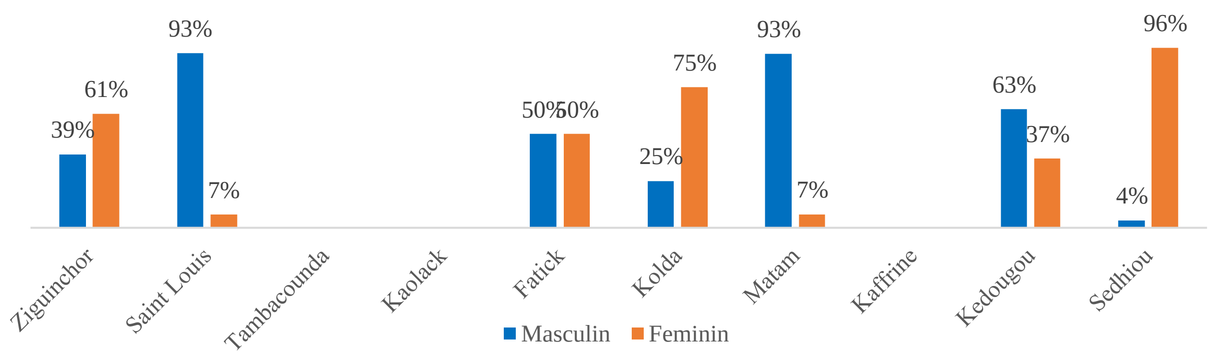
Figure 5. Respondents by gender.



Source: Authors, EAA 2020-2021

In the region of Sédhiou 96% of plots are managed by women, followed by Kolda (75%); Ziguinchor (61%) and Fatick (50%). This means that in Casamance (Sédhiou, Ziguinchor and Kolda), rice growing is mainly practiced by women. In the rest of the country (Saint Louis, Matam and Kédougou), rice cultivation is primarily on plots managed by men (Figure 6).

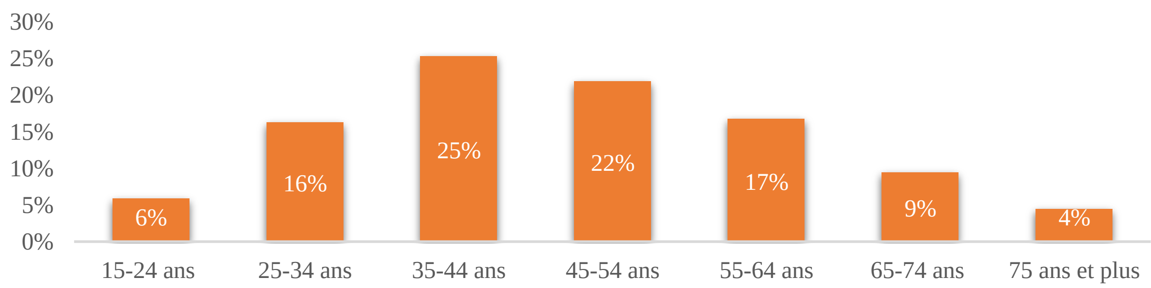
Figure 6. Respondents by gender and region.



Source: Authors, EAA 2020-2021

The distribution of plot managers by age group (Figure 7) reveals that those aged between 35 and 44 are in the majority. They represent 25% of plot managers, followed by the age group 45-54 at 22% and ages 55-64 (17%). This means that the majority of farmers are relatively young.

Figure 7. Distribution of plot manager respondents by age.



Source: Authors, EAA 2020-2021

The distribution of respondents according to the marital status of the plot manager shows a predominance of married people (84%) followed by widowers who represent 11%. The share of single and divorced plot managers is very low, accounting for 4% and 1% respectively.

Access to credit is a major issue for smallholder farmers in Senegal. Indeed, only 8% of plot managers received loans during the 2020-2021 agricultural campaign. The majority of producers are forced to resort to self-financing to allow the continuity of their activities. This limits the modernization of the sector and its expansion insofar as producers constrained by financing are forced to use traditional agricultural equipment without having access to modern production equipment and agricultural mechanization.

The average age of plot managers is 46 years old, ranging between 16 and 85 years old (Table 2). On average, each household has 11 people. The average size of the plots is 0.45 ha, ranging between 0.01 and 36 ha. On average, each plot manager operates 3 plots of land. The maximum number of plots operated per manager is 15. The average area operated per plot manager is 1 ha, and the average area farmed per household is 2 ha. Each household farms an average of 4 plots of land. The average rice yield remains low and equal to 2.29 t/ha, with peaks that can reach 9.34 t/ha. On average, the seed rate applied is 85 kg/ha. This is slightly higher than the standard recommended by ISRA which is 80 kg/ha.

Table 2. Descriptive statistics.

Variable	Obs.	Mean	Std. Dev	Min	Max
Age	1481	46	14.819	16	85
Household size	1481	11	6.917	1	49
Plot size (Ha)	1481	0.45	1.352	0.01	36
Yield (T/Ha)	393	2.26	1.843	0.02	9.04
Seed rate (Kg/Ha)	1481	85	23.722	30	180
Area cultivated (Ha)	1481	1	2.213	0.013	36
Farm size (Ha)	1481	2	2.857	0.017	38
Number of parcels managed	1481	3	2.039	1	10
Number of parcels (total HH)	1481	4	3.065	1	15

Source: Authors, EAA 2020-2021

The vast majority of plot managers (89.94%) claimed to have operated plots with an area less than or equal to 2 ha. Only 1.01% of them farm plots greater than or equal to 5 ha. This means that the majority of rice farmers in Senegal cultivate small plots (Table 3).

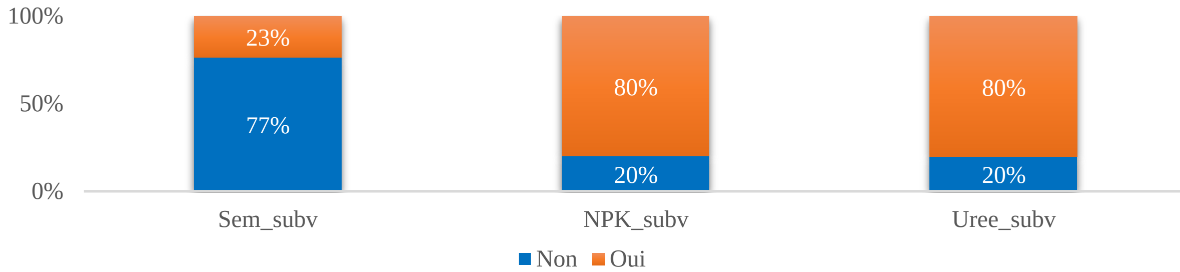
Table 3. Crop parcels reported by size.

Parcel size (Ha)	Freq.	Percent	Cum.
1	1,109	74.88	74.88
2	223	15.06	89.94
3	125	8.44	98.38
4	9	0.61	98.99
5 or more	15	1.01	100.00
Total	1,481	100.00	

Source: Authors, EAA 2020-2021

The distribution of respondents according to the use of subsidized inputs (Figure 8) revealed that the vast majority of plot managers (77%) answered that they had not used subsidized seeds. This means that the use of subsidized seeds in the production process is relatively low (23%). This could reflect scarcity of supply, or could be explained by the fact that a large quantity of subsidized seeds is directly consumed by households or resold. With regard to NPK and urea fertilizers, the majority of plot managers (80%) said they had used them during the 2020-2021 agricultural campaign.

Figure 8. Use of subsidized inputs (seed, NPK, urea) among sample respondents.



Source: Authors, EAA 2020-2021

5.2 SFA model results

The first step of the SFA model consisted in estimating rice production (dependent variable) from a set of classic inputs (independent variables) drawn from the literature.

Table 4. Results of the Stochastic Frontier Analysis model estimation.

Yield (ln)	Parameters	Coef.	Std. Err.	P-Value
Constant	β_0	1.823	0.25	0.000***
Seed rate (ln)	β_1	0.049	0.047	0.297
Plot area (ln)	β_2	-0.328	0.056	0.000***
NPK (ln)	β_3	0.010	0.038	0.802
Urea (ln)	β_4	-0.111	0.035	0.001***
Household size (ln)	β_5	-0.285	0.074	0.000***

Note: ***p<0.01; **p<0.05; *p<0.10 ; n=393
Source: Authors, EAA 2020-2021

The results in Table 4 indicate that the size of the plot is negatively associated with rice yield, with a 1% increase in land area associated with reduced yield by 0.328%. This could be explained by the fact that the vast majority of producers in the sample do not have the labor, material and financial means to make larger farms profitable. The model also suggests that a 1% increase in urea use would lead to a drop in yield of 0.111%. This could be explained by the fact that NPK and urea are substitutes (meaning more use of urea is linked with less use of NPK), or that urea use is more likely on less fertile plots as a coping strategy. Seed and NPK application levels appear to have no effect on rice yield.

Farm labor as measured by household size also shows a negative association with yield. A 1% increase in household members reduces yield by 0.285%. This result could reflect parents investing more time and resources in their children than in the fields.

5.3 Technical efficiency of rice farmers in Senegal

Table 5 shows that out of the 393 plots considered in the model, there is an average technical efficiency score of 0.545, with a range between 0.113 and 0.987. This suggests that overall rice farmers in Senegal could improve their current production level by 45.5% while keeping the level of inputs unchanged. This result is very consistent with that of Bèye et al. (2018) who found a technical efficiency score of 0.534 on family farmers in Senegal.

Table 5. Technical efficiency scores of rice producers in Senegal.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Efficiency	393	0.545	0.224	0.113	0.987

Note: Efficiency indicates the technical efficiency level
Source: Authors, EAA 2020-2021

The second step of the model was to identify the variables likely to influence the technical inefficiency of rice farmers. The results of the regression of the independent variables on technical inefficiency are presented in Table 6.

Table 6. Results of the technical inefficiency model.

Inefficiency	Parameters	Coef.	Std. Err.	P-Value
Constant	δ_0	0.511	0.077	0.000***
Seed subsidy	δ_1	-0.105	0.038	0.006***
NPK subsidy	δ_2	0.025	0.032	0.437
Urea subsidy	δ_3	-0.051	0.029	0.085*
Organic fertilizer	δ_4	0.044	0.023	0.057*
Herbicides	δ_5	0.000	0.026	0.998
Credit	δ_6	-0.049	0.035	0.168
Age	δ_7	0.003	0.001	0.000***
Sex (Female)	δ_8	0.096	0.037	0.01***
Marital status (Married)	δ_9	-0.125	0.067	0.062*
Education (No education)	δ_{10}	-0.122	0.028	0.000***

Note: ***p<0.01; **p<0.05; *p<0.10 ; n=393
Source: Authors, EAA 2020-2021

Estimation of the technical inefficiency model revealed that seed and urea subsidies both significantly reduce technical inefficiency (that is, the subsidies appear to improve the technical efficiency of rice farmers in the sample). Indeed, the fact that the farmer uses subsidized seeds reduces his production inefficiency by 10.5%. Also, the use of subsidized urea reduces operator inefficiency by 5.1%. This result is consistent with that of Seck (2016) who states that the fertilizer subsidy program improved the productive performance of rice farmers in the Senegal River Valley (VFS).

On the other hand, the model revealed that the use of subsidized NPK has no effect on rice production performance. Regarding organic fertilizer, the model revealed that its use seems to worsen the technical inefficiency of the farmer by 4.4%. The results of the estimation also revealed that the use of herbicides in the plot has no effect on the technical efficiency.

Regarding socio-demographic factors, the results revealed that older respondents are associatted with more severe technical inefficiency, on average, consistent with the hypothesis that young people are likely to be more technically efficient than older people. Female-headed households similarly experience greater levels of technical inefficiency by 9.6%. This could reflect rural women spending more time in household chores than in field work; women also have more difficult access to financing and agricultural equipment. Regarding the marital status of the farmer, the model revealed married rice farmers on average see reduced technical inefficiency by 12.5%. Being in a couple makes it possible to pool resources and help each other in field work. It also allows the exchange of agricultural experience and complementary skills and knowledge.

The results also indicated that having no formal education is associated with improved rice farmer technical inefficiency by 12.2%. Indeed, in rural areas, people who have never studied often take up field work at a young age. This may allow them over time to acquire more experience in the agricultural field than those with more advanced levels of education. Regarding access to credit, the results of the estimation showed no effect on the technical efficiency of rice farmers in Senegal. This result contradicts the findings of Seck (2019) indicating that access to credit improved the productive performance of smallholder farmers in the Senegal River Valley.

VI. CONCLUSION

This study aimed to analyze the effect of seed and fertilizer subsidies (NPK and urea) on the technical efficiency of rice farmers in Senegal. Using data from the Annual Agricultural Survey (EAA) of the Directorate of Analysis, Forecasting and Agricultural Statistics of Senegal (DAPSA), the results of the SFA model estimation revealed that rice farmers in Senegal have averaged a technical efficiency score of 0.545. This indicates that they can increase their current level of production by 45.5% while keeping the level of input unchanged.

Access to subsidies – for seed and urea – appears linked to improvements in technical efficiency. Estimation of a technical inefficiency model suggest use of subsidized seeds reduces rice production inefficiency by 10.5%, and the use of subsidized urea reduces inefficiency by 5.1%. These results are largely consistent with Seck (2016) who found the fertilizer subsidy program improved the productive performance of rice farmers in the Senegal River Valley. However, we also find particularly severe barriers to improved efficiency among older farmers and women, suggesting targeted supports may be necessary alongside general subsidy programming.

6.1 Policy recommendations

In light of the results of this study, we make the following recommendations:

- Insofar as the study has shown that the input subsidy program effectively makes it possible to significantly improve the productive performance of rice farmers in Senegal, the State must increase its efforts in order to enable producers to benefit from this program.
- Given the study findings that not all input subsidies are associated with technical productivity gain, particularly the use of NPK subsidies, findings lend support to recent calls to create a rigorous system of management and transparency to fight against the loss and diversion of inputs intended to be allocated to production activities in Senegal.
- Continue to entrust the distribution of subsidized inputs to the Senegal River Delta and Valley Development and Exploitation Company (SAED) and the Agricultural and Industrial Development Company of Senegal (SODAGRI), given its two structures are closely linked to rice farmers and have experience on the ground with program implementation.
- Given particularly severe barriers to improved technical efficiency among older farmers and women, targeted supports may be necessary alongside general subsidy programming.

6.2 Data recommendations

In order to improve the Annual Agricultural Survey (EAA) database in order to facilitate its use, we make the following recommendations:

- Collect information on production per plot (necessary for computing yield by plot) in addition to production per household (which is currently reported). This plot-level data is needed to estimate the plot-level returns to input use, a key component of technical efficiency.
- Given that there are several production measurement units on the survey questionnaire, a reliable set of conversion factors, that is accessible to users, is needed to ensure valid comparisons across regions and households.

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